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Cost and Effectiveness of Hand Harvesting to Control the Eurasian Watermilfoil Population in Upper Saranac Lake, New York

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ABSTRACT

An intensive hand harvesting project was undertaken to achieve whole-lake control of Eurasian watermilfoil in Upper Saranac Lake, New York. Beginning in 2004, six crews of divers hand harvested the entire littoral zone of Upper Saranac Lake twice per summer for three years, after which the harvesting effort was scaled down to a maintenance configuration. Eurasian watermilfoil cover and removal data were collected by the crews, and the process was also monitored using permanent underwater transects to track the Eurasian watermilfoil response to management. Eurasian watermilfoil cover was reduced to rare (<5% cover) for more than 90% of the littoral area, and plant removal decreased from about 16,640 kg in 2004 to 460 kg in 2006, the final year of intensive management. Eurasian watermilfoil density in the transects dropped from 1650 stems/ha (±343 S.E.) in August 2004 to 63 stems/ha (±9.26 S.E.) in August 2006, with similarly low density during the maintenance period. Labor cost averaged $351,748/yr during intensive management and $146,475/yr during the maintenance period. Results indicate that hand harvesting is a viable management technique for achieving whole-lake control of Eurasian watermilfoil; however, successful use of hand harvesting requires a large financial investment.

Key words: Adirondack Park, milfoil, *Myriophyllum spicatum.*

INTRODUCTION

There are approximately 3000 lakes and ponds in New York's Adirondack Park, the largest publicly protected area in the contiguous United States. Eurasian watermilfoil (*Myriophyllum spicatum* L.) has been in the Adirondack Park since at least 1979, when it was first documented in the Chateaugay Lakes by Dr. John Peverly from Cornell University. According to the Adirondack Park Invasive Plant Program (APIPP), Eurasian watermilfoil is the most commonly observed aquatic invasive plant, growing in 48 of 53 lakes and ponds infected with aquatic invasive plants out of 216 surveyed. Management is occurring in approximately 19 of the 48 infested lakes and ponds (H. Smith, personal communication, 12 September 2009).

In the Adirondack Park, hand harvesting and benthic barriers are the most common methods used to manage Eurasian watermilfoil; however, water level draw down is also used for a small number of lakes. Chemical and biological control methods are being considered for use; however, to date, no applicant has successfully obtained a permit for chemical control. According to the Adirondack Park Agency, there is currently one active permit for biological control of Eurasian watermilfoil using grass carp (*Ctenopharyngodon idella*), and a permit for the milfoil moth (*Acentria ephemerella*) was issued several years ago, but the project yielded mixed results (E. Snizek, personal communication, 7 May 2009).

Hand harvesting has been used successfully in Lake George in the southeastern region of the Adirondack Park since 1989 to reduce Eurasian watermilfoil densities at a limited number of sites (Boylen et al. 1996, Eichler et al. 1993, 1995). However, no large-scale hand removal for moderate- to high-density areas has been used to date[2]. The Lake George Association currently reports Eurasian watermilfoil to exist in 157 locations, 24 of which contain dense beds[2], indicating that this aquatic invasive species has continued to expand throughout the lake despite significant effort to control it.

Eurasian watermilfoil was first reported in Upper Saranac Lake in 1996 (Martin 1998). A limited control effort using mainly hand harvesting and some benthic matting was conducted from 1999 through 2003, with about $55,000 expended annually. While localized reductions were achieved, aquatic plant surveys showed Eurasian watermilfoil expansion through the unmanaged areas of the lake.

Recognizing the partial success of the control effort and the documented expansion of Eurasian watermilfoil in other parts of Upper Saranac Lake, members of the lake community developed a new management approach. The new approach was implemented in 2004 and is referenced to herein as the "intensive management effort." This approach called for the selective removal of Eurasian watermilfoil using diver hand harvesting of the entire littoral zone of the lake at least twice each summer for three years. The objective was to achieve an annual maintenance level after three years, defined by expending approximately $150,000/yr in perpetuity to maintain the Eurasian watermilfoil population at a sustained low level.

The intensive management effort in Upper Saranac Lake represents the first attempt in the region at controlling Eurasian watermilfoil in an entire lake using primarily hand har-

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vesting. Our objective was to describe the intensive management approach used to achieve whole-lake control and to provide an evaluation of its efficacy.

MATERIALS AND METHODS

Study Site

Upper Saranac Lake is located in southern Franklin County, New York, and lies entirely within the six million acre Adirondack Park (Figure 1). It has an overall length of 12.1 km, 59.5 km of shoreline, maximum depth of 28.8 m, and a total surface area of 1912 ha. The lake is composed of approximately 483 ha of littoral zone (estimated based on depths <4 m). Three distinct basins (north, middle, and south) occur as a result of depth characteristics and an irregular shoreline, with numerous bays and coves. The lake forms the headwaters of the Saranac River, a major tributary of Lake Champlain, and is a popular recreational resource in the Adirondack region. Upper Saranac Lake is classified as a mesotrophic, soft-water (average alkalinity 8 mg/L as $CaCO_3$), low pH (average pH 6.8) waterbody. Secchi disk values range from 2.9 to 4.9 m with slightly higher transparency in the south basin (Martin 1998). In May 2004, prior to the initiation of this study, 140 benthic barrier mats were installed in the lake and removed the following year. The total area of mat coverage was 0.4 ha and represents 0.08% of the littoral zone of the lake.

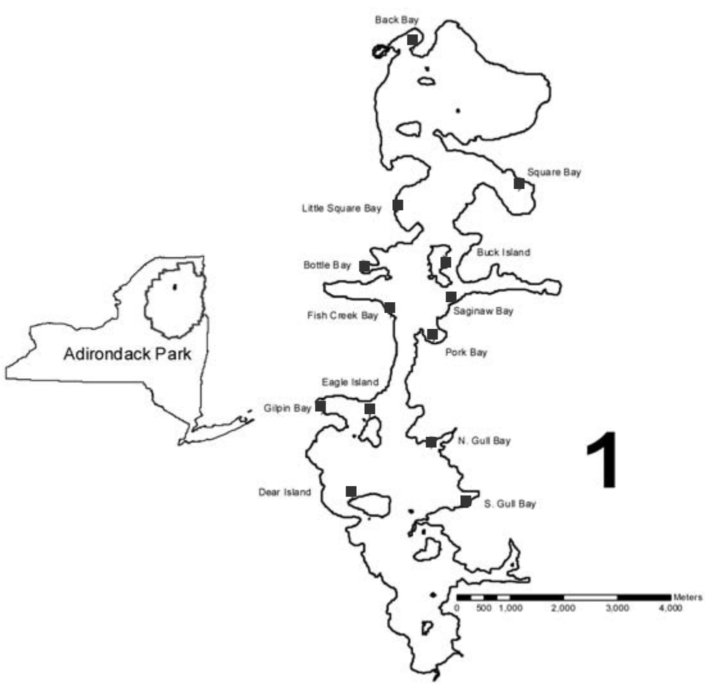

Figure 1. Geographical location of Upper Saranac Lake in the Adirondack Park of New York State. Hand removal of Eurasian watermilfoil was conducted in the lake from 2004 to 2008. The 13 sites with historically high milfoil abundance are indicated as squares along the shoreline; these sites were selected for intensive underwater monitoring.

Harvesting Method

Crew configuration. Two distinct types of harvesting crews were used on the lake. The first were hookah crews, utilized in areas of dense Eurasian watermilfoil growth and typically employing four divers and a top-water person. One of the divers served as supervisor; not only harvesting plants, but also managing the crew, estimating percent cover of Eurasian watermilfoil and recording data. A hookah rig consists of an air compressor with four 45-m long air hoses. A crew can harvest a circular area of approximately 6300 m^2 before moving the hookah rig. At each location, a waypoint was taken with a GPS unit (Etrex Vista, Garmin International Inc., Olathe, KS, USA) prior to harvesting. The supervisor estimated the percent cover of Eurasian watermilfoil following the rating system of Eichler et al. (1995) in Lake George: abundant (>50% bottom cover), common (25-50%), present (15-25%), occasional (5-15%), rare (<5%). Data on percent cover by location were analyzed spatially with GIS software (ArcMap, ESRI, Redlands, CA, USA). Divers then removed all Eurasian watermilfoil from the area, each diver working his/her own quadrate. Divers took special care to remove all of the plant material including roots, thus substantially limiting the rate of regrowth (Nicholson 1981). Divers stuffed all plant material into mesh dive bags, which were brought to the surface when full. The mesh bags have a diameter of 28 cm and a depth of 80 cm. Full bags averaged 9.2 kg (±2.5 SD, n = 50). Average bag weight was used to convert total number of bags harvested to kg wet weight removed from the lake. Plant fragments produced by the harvesting operation were collected by the top-water personnel. Time spent harvesting and number of bags removed was recorded for each location.

The second crew type employed SCUBA in areas of low density growth and typically included three people, two divers and a top-water person. The tank crews systematically swam the littoral zone from shallow to deep water, harvesting occasional plants and keeping data on location, time, percent cover, and total number of bags removed in the same manner as the hookah crews.

Harvesting Effort. Eurasian watermilfoil harvesting occurred from 1 June through mid-August 2004-2008. The objective was to circumnavigate the entire littoral zone of the lake at least twice during each year, with more frequent visits to sites with high Eurasian watermilfoil densities. The intensive management period was from 2004 to 2006. During these three years there were typically four hookah crews (roughly 20 workers) and two tank crews (roughly six workers) harvesting in the lake. The approach was to reduce the effort (man*days) needed to survey, harvest, and collect data by 50% in 2007, and again in 2006 as the lake entered into the maintenance period. In 2007 there were two hookah crews and in 2008 there was only one crew. Due to the subsequent reduction in Eurasian watermilfoil densities, hookah crews shifted to an approach where divers swam together in a line along the littoral zone removing isolated pockets of Eurasian watermilfoil.

Assessment Method

To assess large scale hand harvesting as a viable tool for Eurasian watermilfoil management, 13 sites with historically high Eurasian watermilfoil densities were selected for intensive evaluation (Figure 1). At each site a combination of transect and fixed-plot methods were used to monitor the presence and abundance of Eurasian watermilfoil, similar to methods described by Madsen et al. (1988, 1991) and Eichler et al. (1995).

2004 Assessment. Four transect lines were established at each of the 13 sites in 2004 with the exception of the Gull Bay and Deer Island sites, which had two and three transects, respectively. Each transect was laid out perpendicular to the shoreline in water depths of 1 to 5 m, a range known to bracket the extent of Eurasian watermilfoil growth, and consistent with work done on other regional lakes such as Lake George (Madsen et al. 1988, Eichler et al. 1995). At some locations the lake bottom had very little slope, in which case 45-m long transects were established, and the corresponding depths at the endpoints were recorded. The endpoints of each transect line were marked permanently with rebar and PVC pipe and geo-referenced with a sub-meter GPS unit (ProXR, Trimble, Sunnyvale, CA, USA). In August and September 2004 a diver recorded the number of Eurasian watermilfoil stems in a 1-m^2 plot at 1, 3, and 5 m depth along each transect line. Each set of measurements were collected in a one-week period.

2005-2008 Assessment. To increase the sampling area, transect lines were installed permanently in May 2005. Nylon rope with flagging every 3 m was fixed to the bottom at each site. Approximately 3700 m of nylon line was fixed to the lake bottom. Instead of only enumerating stems/m^2 at 1, 3, and 5 m depth intervals, as was done in 2004, Eurasian watermilfoil stems were counted in 2-m wide bands in each 3 m transect segment. This change increased the bottom surface area sampled for Eurasian watermilfoil and allowed more accurate scaling of Eurasian watermilfoil stem counts. In addition, the frequency of transect measurements was increased from August and September to May through September in 2005 and May through October in 2006-2008.

All study sites received the same Eurasian watermilfoil removal effort as the rest of the lake; the dive crews harvested all Eurasian watermilfoil twice during each year, once at the end of June and again in early August. Data from each transect were compiled at the site level. Eurasian watermilfoil density was estimated by averaging the number of Eurasian watermilfoil stems per hectare across all 13 sites.

RESULTS AND DISCUSSION

Harvesting effort remained relatively constant during the intensive management period, averaging 1463 man*days per year at an average cost of US$728/ha of littoral zone (Table 1). Eurasian watermilfoil harvest was greatest in 2004, with more than 16,643 kg removed. In 2005 there was a 67% reduction in the amount of Eurasian watermilfoil removed, followed by a further reduction of 97% in 2006. These results indicate that the intensive hand harvesting effort resulted in a rapid decrease of Eurasian watermilfoil and was over 97% effective in the removal of Eurasian watermilfoil from the lake. In 2007, the first year of the maintenance period, total removal was similar to that of 2006 (386 vs. 460 kg); however, this removal was achieved with a 50% reduction in man*days, indicating a 50% reduction in the number of hours needed to harvest the entire littoral zone of the lake. In 2008 the effort was again reduced by 50% and 239 kg of Eurasian watermilfoil were removed. Similar results were reported for hand harvesting in Lake George, New York. Boylen et al. (1996) reported hand harvesting to be 80% effective in removing Eurasian watermilfoil from 14 infested sites during 1989-1990, despite a 56% reduction in effort between years.

The cost/kg of Eurasian watermilfoil removed increased with each year of management, starting at $23/kg during the first year of intensive management and reaching $485/kg in 2008 (Table 1). This is to be expected due to a minimum set up and survey time required to inspect the entire littoral zone, no matter what abundance of Eurasian watermilfoil is encountered; thus, harvest per unit effort will continue to increase as abundance of Eurasian watermilfoil goes down. Prioritizing areas to be inspected annually could further reduce survey times and thus costs. Compared to the other years, the cost/kg removed in 2006 was considerably higher because the management crews were over prepared for relatively low milfoil density. This suggests that objectives for the intensive management period were achieved during the first two years and that a third year of intensive management may not have been warranted.

A comparison of lake wide Eurasian watermilfoil cover between years further illustrates the reduction achieved during the harvesting effort (Table 2). In 2004, Eurasian watermilfoil was found to be either common or abundant in 16% of the lakes littoral area. At the end of the intensive harvesting period, Eurasian watermilfoil was common in only 3% of the

TABLE 1. SUMMARY OF HAND HARVESTING EFFORT, LABOR COST (US$), AND WET WEIGHT OF EURASIAN WATERMILFOIL REMOVAL IN UPPER SARANAC LAKE, NY, FROM 2004 THROUGH 2008.

Year	Start Date	Man*days	Payroll $	$/ ha	kg removed	$/kg
			Intensive management period			
2004	May 23	1618	384,389	796	16,643	23
2005	May 22	1334	324,890	672	5,419	60
2006	May 21	1436	345,965	716	460	752
			Maintenance period			
2007	June 1	723	176,951	366	386	458
2008	June 9	420	116,000	240	239	485

Table 2. Percent of littoral area occupied by Eurasian watermilfoil by cover class in Upper Saranac Lake, NY, from 2004 through 2008. Cover classes are based on percent of bottom covered.

Year	Abundant (>50%)	Common (25-50%)	Occasional (5-15%)	Rare or Absent (<5%)
		intensive mgt period		
2004	3	13	47	37
2005	0	7	31	63
2006	0	3	5	92
		maintenance period		
2007	0	0	6	94
2008	0	0	8	92

littoral area, and nowhere was percent cover recorded as abundant. At the end of this study, Eurasian watermilfoil was rare in 92% of the littoral area, and did not achieve common or abundant cover anywhere in the lake.

Finally, results from the 13 monitoring sites corroborate the validity of hand harvesting as a tool for Eurasian watermilfoil management (Figure 2). Density was greatest in August of 2004 with an average of 1650 (±343 S.E.) stems/ha. A steep decline in stem density occurred during the intensive management period with a reduction of 93% by October 2006. Eurasian watermilfoil densities remained consistently low during the maintenance period, ranging from 23 to 75 stems/ha in 2007 and from 8 to 113 stems/ha in 2008. Initially in 2004, 10 of the 13 sites had established Eurasian watermilfoil populations. In 2005 this number increased to 12 sites, but was reduced to four sites by the end of the intensive period. The number of sites with Eurasian watermilfoil has trended up during the maintenance period, with the species occurring in eight sites in 2008 (Figure 3). These results indicate that Eurasian watermilfoil is continuing to expand its range in the lake, despite substantial reductions in density, and that recolonization of controlled areas may occur.

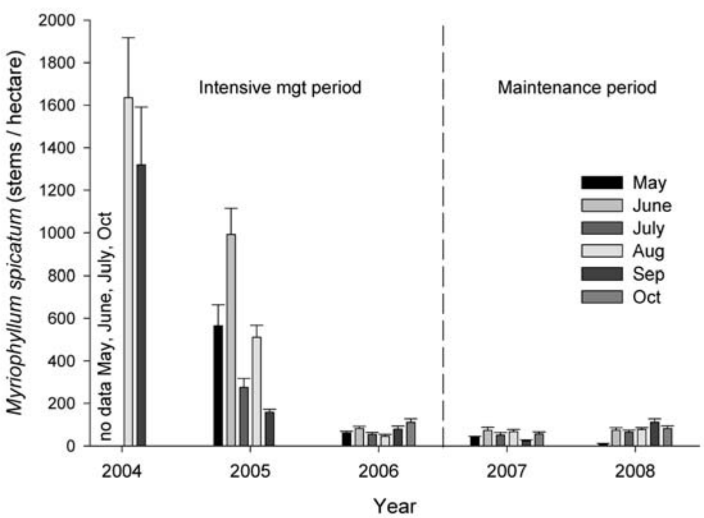

Figure 2. The average density of Eurasian watermilfoil at the 13 underwater monitoring sites in Upper Saranac Lake 2004-2008. Vertical bars represent one standard error (SE) of the mean, n = 13.

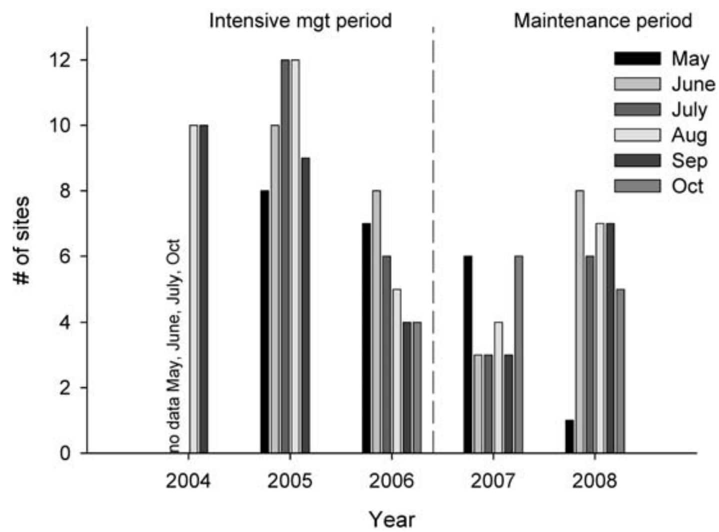

Figure 3. Frequency of occurrence of Eurasian watermilfoil at the 13 underwater monitoring sites in Upper Saranac Lake by month, 2004-2008.

It is highly unlikely that the management approach will eradicate Eurasian watermilfoil from Upper Saranac Lake, but it has reduced the infestation to a level that can be managed within the financial limits defined by the stakeholders. In fact, the greatly reduced density of Eurasian watermilfoil reported in 2008 (Table 2) is comparable to the density reported in 1998 (Martin 1998). Thus, it seems that the management effort has in effect “knocked back” the Eurasian watermilfoil population to the level reported when its presence was first detected in the lake 10 years earlier.

The maintenance cost in 2008 was approximately 33% of the annual average cost of intensive management. If holding the Eurasian watermilfoil population at 1998 levels remains the management goal, then there is no reason to believe that the maintenance cost will decline over time. In fact, given that Eurasian watermilfoil seems to be expanding its range again during the maintenance period, the crew size may be too small to effectively keep the population in check. To limit reinvasion and to control costs, the maintenance plan going forward will integrate intensive monitoring by volunteers and paid staff. New plants detected by the monitors will then be removed by the harvesting crew in a within-lake rapid response mode. If this approach is successful then the maintenance costs will be approximately $120,000/yr in perpetuity.

Regardless of the approach chosen to control Eurasian watermilfoil (or other aquatic invasive plants), management of aquatic invasive plants is an expensive proposition. More than $1.5 million was invested in control in Upper Saranac Lake from 1999 through 2008, and though results show that the management effort has succeeded thus far, the high level of investment needed may exceed the ability of stakeholders at other infested lakes. With 29 of the 48 lakes known to support Eurasian watermilfoil in the Adirondack Park currently not being managed, and considering that raising the funds needed for control will be a great challenge for most lake groups, far more emphasis should be placed on spread prevention. Though not conventionally thought of as a management technique, spread prevention is widely believed to be the most cost effective method for controlling invasive species. Well-coordinated volunteer or paid boat inspector programs at launch sites provide protection for as yet uninfected lakes.

The results from this study demonstrate that hand harvesting can be used to achieve whole-lake Eurasian watermilfoil control in large lakes. The financial investment required to support intensive hand harvesting is significant and will vary greatly depending on the extent of infestation. For longer term budgeting purposes, stakeholders need to also consider the annual costs of maintenance control. Until other more efficacious methods of control are proven and permitted for use in the Adirondack Park, hand harvesting should be considered a viable management tool for whole-lake control of Eurasian watermilfoil in Adirondack lakes and ponds.

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Curt Stiles, Tom Chipperfield, and Tim LaDue were instrumental in helping to design and implement this project. This work would not have been possible without the enthusiastic and conscientious field assistance provided by Paul Smith's College graduates, Kathy Bozony and Chris Audette. Financial support for this project was provided by the Upper Saranac Lake Foundation.

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Assessment of Herbicide Efficacy on Eurasian Watermilfoil and Impacts to the Native Submersed Plant Community in Hayden Lake, Idaho, USA

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ABSTRACT

The presence of Eurasian watermilfoil (*Myriophyllum spicatum* L.) in aquatic systems has resulted in adverse impacts to native plant communities, ecosystem function, and water resource uses. Eurasian watermilfoil in Hayden Lake, Idaho, has spread rapidly, impacting the native plant community and recreational uses of the lake. Point intercept surveys were conducted to determine the current composition of the plant community and to assess the efficacy of triclopyr and 2,4-D herbicide treatments on Eurasian watermilfoil during the year of treatment. Twenty-two aquatic plant species were identified during four surveys (two of the littoral zone and two focused on herbicide treated areas) conducted between June and September 2007. The presence of Eurasian watermilfoil was reduced in all treated areas by 88% ($p < 0.01$) 5 weeks after treatment. There was no difference ($p = 0.81$) in the efficacy between triclopyr and 2,4-D for control of Eurasian watermilfoil. The use of herbicides had no significant deleterious impacts on the native plant community. The percent occurrence of large-leaved pondweed (*Potamogeton amplifolius* Tuckerm.), Robbins' pondweed (*Potamogeton robbinsii* Oakes), and wild celery (*Vallisneria americana* Michx.) increased after treatment ($p < 0.01$). Future triclopyr and 2,4-D applications should have minimal to no negative impact on the native plant community in Hayden Lake due to the dominance of monocotyledon species among the native vegetation, which are generally tolerant to these herbicides.

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Key words: 2,4-D, *Myriophyllum spicatum*, Navigate, point intercept, Renovate3®, species richness, triclopyr.

INTRODUCTION

Hayden Lake is located in northern Idaho and has been invaded and colonized by Eurasian watermilfoil (*Myriophyllum spicatum* L.) in the past decade. Eurasian watermilfoil was first identified in Hayden Lake in 1998 by the Kootenai County Noxious Weed Program, prompting an operational control program beginning in 1999. During the 1998-1999 growing season there was approximately 243 ha (600 ac) of Eurasian watermilfoil, which represented roughly 16% of the total surface area of Hayden Lake. The initial introduction, spread, and possible reintroduction of Eurasian watermilfoil is likely attributed to increased disturbance within the lake and watershed of Hayden Lake. The shoreline of Hayden Lake is becoming suburbanized with increases in houses, parks, beaches, and impermeable surfaces. This development results in greater runoff into the lake and greater use of the lake for recreation (Hayden Lake Watershed Association 2008). As lake shores become more developed and recreation on the water increases, the level of disturbance also increases, which may result in reductions in native species. Removal or reductions in native species opens a niche for fast-growing colonizing species like Eurasian watermilfoil (Davies et al. 2005, Lockwood et al. 2005, Capers et al. 2007). Also, in recent years, a growing tourist industry has attracted an estimated 800,000 people each year to the region (Hayden Lake Watershed Association 2008), further putting the lake at risk to potential invasion by non-native species.

The threats posed by Eurasian watermilfoil to Hayden Lake and other water bodies in the state have prompted the Idaho State Department of Agriculture (ISDA), in cooperation with the Idaho Invasive Species Council, to develop a Eurasian watermilfoil eradication program (ISDA 2007). As part of this program, suspected waterbodies are being monitored to detect the presence of Eurasian watermilfoil, and those already infested are being monitored to document the extent and spread of Eurasian watermilfoil. The point-intercept method was chosen as the sampling protocol for the program due to the simplicity of data collection and the ability to conduct a quantitative statistical assessment of plant control techniques.

Management of Eurasian watermilfoil from 1999 to 2009 in Hayden Lake included the use of herbicides, diver-operated suction dredging, and bottom barriers. Over the past 10 years, 583 ha (1441 ac) of Eurasian watermilfoil has been managed at an average cost of \$2074 ha^{-1} (\$838 $acre^{-1}$; Inland Empire Cooperative Weed Management Area, unpublished data). In 2007, the auxin-mimicking herbicides triclopyr (triethylamine (TEA) salt of [(3,5,6-trichloro-2-pyridinyl) oxy]acetic acid) and 2,4-D (Butoxyethyl ester of (2,4-dichlorophenoxy) acetic acid) were selected for controlling Eurasian watermilfoil in Hayden Lake. Triclopyr and 2,4-D have been used in small-plot and whole-lake management programs to control Eurasian watermilfoil and in many instances have shown considerable selectively in removing Eurasian watermilfoil with little to no impact on native plant communities (Getsinger et al. 1982, 1997, 2000, Parsons et al. 2001, Poovey et al. 2004).

While much is known about the use patterns of 2,4-D and triclopyr on an anecdotal basis, there are relatively few published accounts of case studies using these products. The objectives of this study were to (1) conduct early and late season surveys of the littoral zone of Hayden Lake to assess the current plant community and (2) conduct pre- and post-herbicide treatment surveys to assess the level of control of Eurasian watermilfoil and impacts on nontarget native plant species throughout the lake where treatments using triclopyr and 2,4-D were performed.

MATERIALS AND METHODS

Study Site

Hayden Lake (47°46'1.167"N; 116°42'24.165"W) is located in northern Idaho and is approximately 1568 ha in total area. Hayden Lake has a maximum depth of 54 m and mean depth of 28 m (Bellatty 1990). The major land use surrounding the lake is agriculture and grazing. There are approximately 43 km of shoreline, of which more than 85% is developed (Bellatty 1990). The primary uses of the lake are recreational including boating, skiing, and fishing. Hayden Lake is oligotrophic with water clarity (Secchi depths) exceeding 7 m, and the lake is considered to be nutrient poor with total nitrogen ($NO_2 + NO_3$) <0.01 mg/L and total phosphorus <0.009 mg/L (Bellatty 1990, Hayden Lake Watershed Association 2005, 2006). In 2006, chlorophyll *a* concentrations were <0.002 mg/L, and dissolved oxygen ranged from 8.4 to 11.7 mg/L (Hayden Lake Watershed Association 2006). Historically, conductance was recorded to be 56 to 60 µmhos, total alkalinity as $CaCO_3$ was approximately 24 to 26 mg/L, and water pH ranged from 7.0 to 7.7 (Bellatty 1990).

Littoral Zone Surveys

The point intercept survey method was used to determine the presence of aquatic plants in the littoral zone of Hayden Lake on a 200-m grid (Madsen 1999). The littoral zone was defined using the 5-m depth contour of the lake as determined by the Idaho State Department of Agriculture. An early season survey of the littoral zone consisting of 104 sample points was conducted in June of 2007 (Figure 1). These same sample points were revisited in September 2007 to assess late season changes in the plant community. The surveys were conducted by boat using a Trimble AgGPS106™ receiver connected to a Panasonic Toughbook computer to achieve 1-3 m survey accuracy. At each survey point, a weighted plant rake was deployed twice to determine the presence and identification of aquatic plant species. Additionally, the depth at each point was recorded using a depth finder mounted to the hull of the boat.

Spatial data collected during the surveys were recorded in the computer using FarmWorks Site Mate® software. Data were recorded in database templates using specific pick lists constructed for each survey. Site Mate® provided an environment for displaying geographic and attribute data and enabled navigation to specific locations on the lake (Wersal et al. 2006a, 2007). Survey data were reported as the percent occurrence for each plant species. Species richness was cal-

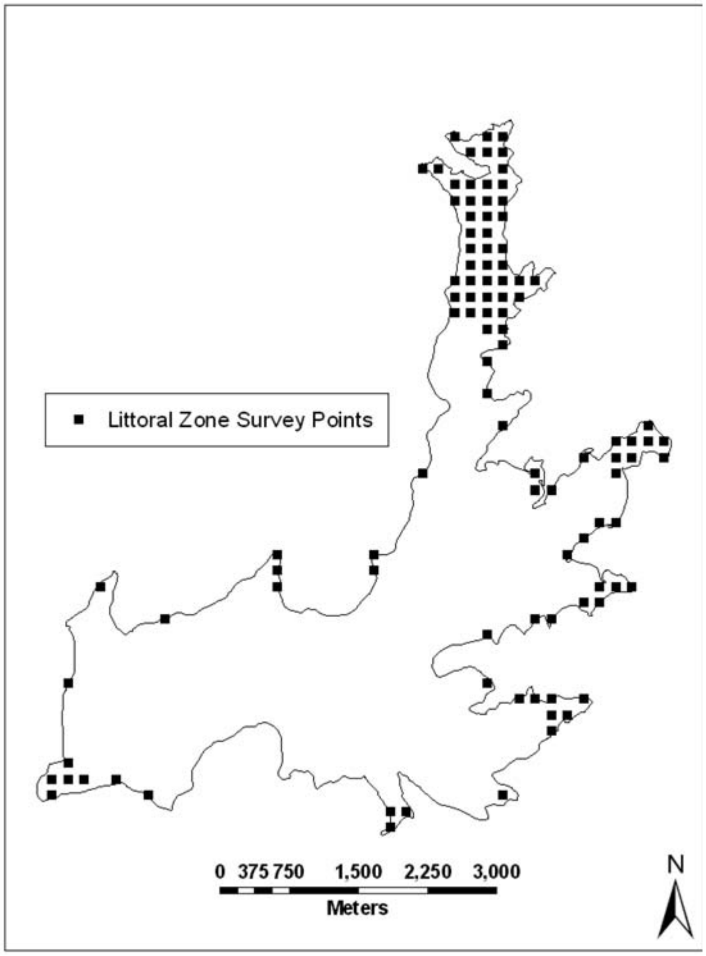

Figure 1. Survey points sampled during the littoral surveys of Hayden Lake, ID, June and September 2007.

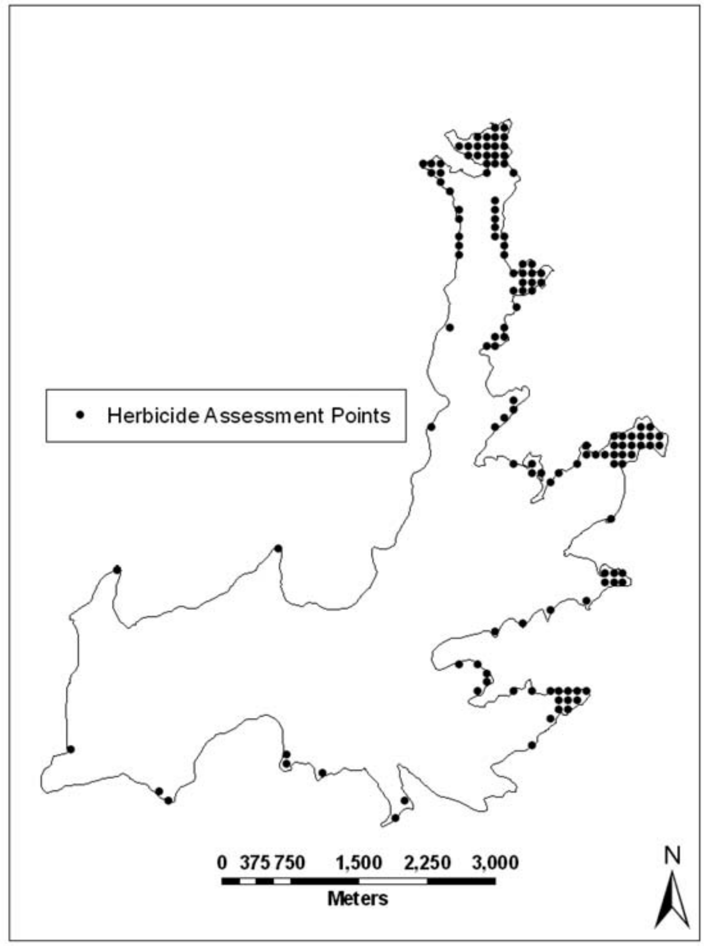

Figure 2. Survey points sampled during the pre and post treatment assessment of Hayden Lake, ID, June and September 2007.

culated as the mean number of species present at each point and presented as the mean (±1 SE) of all species observed at each point.

Herbicide Assessment

Herbicide assessment surveys were conducted similar to the littoral surveys; however, a 100-m grid was used to increase sampling intensity in the areas of Eurasian watermilfoil control (Figure 2). The pretreatment survey was conducted in June 2007 and consisted of 140 points. Herbicide treatments were made on 30 and 31 July 2007. The post-treatment survey was conducted in September 2007, 5 weeks after treatment (WAT) using the same points as the pretreatment survey.

The assessment surveys evaluated the effectiveness of triclopyr applied as liquid Renovate3® and 2,4-D applied as granular Navigate® for the control of Eurasian watermilfoil (Figure 3). Triclopyr was applied as a subsurface application to achieve a target concentration of 1.5 mg ae L^{-1} (mg acid equivalent per liter). The 2,4-D was applied using a granular spreader at rate of 112.3 to 168.0 kg ha^{-1} to achieve a target concentration of 1.5 mg ae L^{-1}. All applications were performed by a licensed commercial applicator. Because Hayden Lake is very deep, the water temperature does not warm sufficiently to allow plant growth until late June or early July. The applications in late July are an appropriate time to target actively growing plants. Water samples were collected by the Kootenai County Weed Board at 1 and 2 days after treatment (DAT) for triclopyr applications and 1, 2, 3, 14, and 42 DAT for most areas treated with 2,4-D. The samples were shipped to Anatek Labs (Moscow, ID) for herbicide residue analyses. Analytical methods followed those outlined in EPA 8321B, high performance liquid chromatography.

Statistical Analyses

Eurasian watermilfoil control was evaluated using McNemar's Test for dichotomous response variables using SAS to analyze differences in the presence of Eurasian watermilfoil between the pre- and post-treatment surveys. McNemar's Test assesses differences in the correlated proportions within a given data set between variables that are not independent (i.e., sampling the same points over time; Stokes et al. 2000, Wersal et al. 2006b, Madsen et al. 2008). The same analysis was conducted to compare the efficacy of triclopyr and 2,4-D

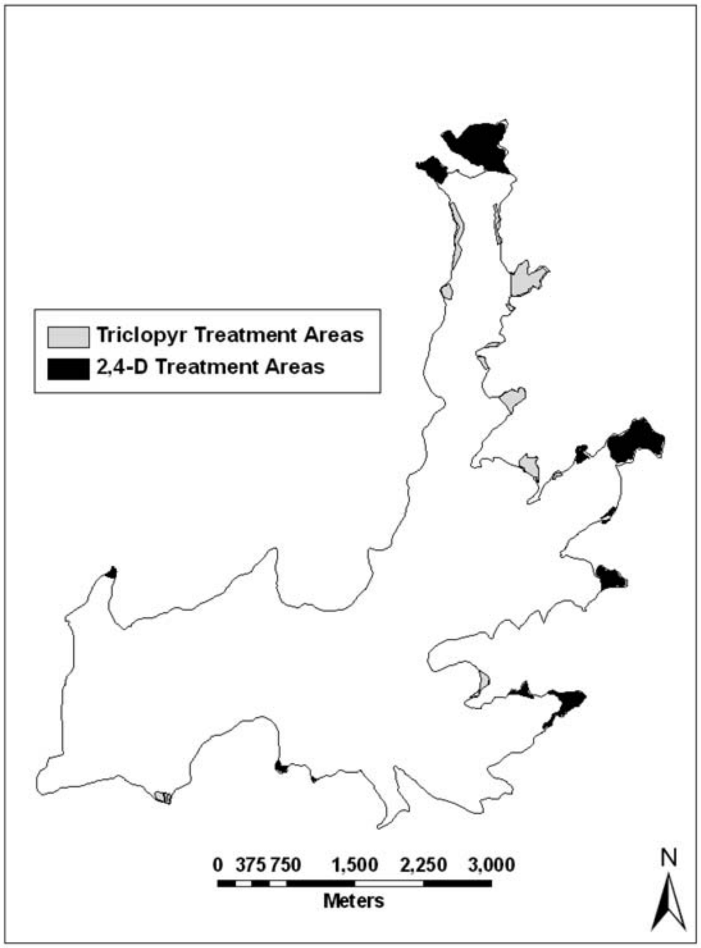

Figure 3. Eurasian watermilfoil herbicide treatment areas on Hayden Lake, ID, 2007.

for treating Eurasian watermilfoil. A paired-T test was used to assess differences in littoral native species richness and differences in native species richness for each herbicide between the pre- and post-treatment surveys (Statistix 8.0; Analytical Software 2003). All analyses were conducted at a $p = 0.05$ level of significance.

RESULTS AND DISCUSSION

Littoral Zone Surveys

During the initial survey of Hayden Lake we observed 18 different species of aquatic plants, with 17 species considered native (Table 1). Wild celery (*Vallisneria americana* Michx.) was considered a native species for the purposes of our analyses, although there is debate as to whether this species is native to the Northwestern United States. The United States Department of Agriculture (USDA 2009) reports wild celery to be native to the lower 48 States. Crow and Hellquist (2000) report wild celery to be introduced to Washington with no mention of other western states. The littoral zone was dominated by pondweed (*Potamogeton*) species, particularly Robbins' pondweed (*Potamogeton robbinsii* Oakes) and large-leaved pondweed (*Potamogeton amplifolius* Tuckerm.). Robbins' pondweed had a frequency of occurrence of 52% and 66% for the early and late season surveys, respectively. Large-leaved pondweed had a frequency of occurrence of 31% and 42% during this same time period.

Native plant species richness increased ($p < 0.01$) from 1.5 species per point during the early season survey to 2.1 species per point during the late season survey. We attribute some of the increase in species richness to the seasonality of native species, especially increases in the presence of some pondweeds. Pondweeds are adapted to grow in low light environments and likely expanded into deeper water habitats as the growing season progressed and temperatures increased, stimulating propagule germination and growth (Spence and Chrystal 1970a, 1970b, Madsen and Adams 1989, Wersal et al. 2006b). Alternatively, Eurasian watermilfoil had a frequency of occurrence of 15% during the early season survey and was observed at <1% of the points during the late season survey. The majority of Eurasian watermilfoil was located in areas of the lake targeted specifically for herbicide applications; therefore, a reduction in species presence is attributed to the use of herbicides and not natural senescence. Eurasian watermilfoil populations in northern areas such as Lake Washington, Washington (Perkins and Sytsma 1987) or Buckhorn Lake, Ontario (Painter 1988) typically are at or near their biomass peak during late summer (Aug and Sep).

Herbicide Assessment

A total of 83 ha (26 ha triclopyr, 57 ha 2,4-D) of Eurasian watermilfoil was treated with herbicides in Hayden Lake during the 2007 season. Water samples collected 1 and 2 d after herbicide applications indicated that measured concentrations of triclopyr were low in all treated areas, indicating rapid degradation or dissipation of the herbicide, considering the target rate was 1.5 mg ae L^{-1} (Table 2). These findings are consistent with other field trials using liquid triclopyr where highest concentrations in treated areas were observed between 4 and 8 h after application, followed by rapid (70 to 90%) degradation and dissipation within 24 h after application (Getsinger et al. 1997, 2000, Poovey et al. 2004). Triclopyr degradation in lakes and ponds is rapid, with half-lives ranging from 0.5 to 7.5 d, depending on degree of water exchange at the treated locations (Woodburn et al. 1993, Petty et al. 2001, 2003). However, overall control of Eurasian watermilfoil in triclopyr plots (26 ha) was 91%.

The presence of Eurasian watermilfoil was reduced in all treated areas by 88% ($p < 0.01$) from the pretreatment survey to the post-treatment survey (Table 3). There was no difference ($p = 0.81$) in the reduction of Eurasian watermilfoil between the triclopyr and 2,4-D treated areas. The use of triclopyr resulted in 91% control of Eurasian watermilfoil at 5 WAT. Similar results were achieved in the Pend Oreille River, Washington, where overall biomass of Eurasian watermilfoil was reduced by 99% within the year of treatment and maintained 99% and 72% control in the treated areas at 1 year after treatment (Getsinger et al. 1997). In Lake Minnetonka, Minnesota, Eurasian watermilfoil was significantly reduced within the year of treatment through the use of triclopyr (Getsinger et al. 2000, Poovey et al. 2004).

Table 1. Frequency of occurrence of aquatic plant species observed during the early and late season littoral surveys of Hayden Lake, 2007. Water depth and species richness are reported as the mean ±1 SE. Significance values were determined using the McNemar's Test at p = 0.05; p-values could not be computed for those species with a 0% occurrence reported during either survey.

Species	Common Name	% Occurrence Early Season	% Occurrence Late Season	p-value
Ceratophyllum demersum L.	Coontail	10	16	0.15
Chara sp.	Muskgrass	3	5	0.41
Elodea canadensis Michx.	Elodea	20	21	0.99
Myriophyllum sibiricum Komarov	Northern watermilfoil	0	2	0.56
Myriophyllum spicatum L.	Eurasian watermilfoil	15	<1	<0.01
Najas flexilis (Willd.) Rostk. & Schmidt	Slender naiad, bushy pondweed	0	2	—
Nitella sp.	Nitella	6	3	0.10
Nuphar lutea L.	Yellow pond-lily	2	3	0.65
Potamogeton amplifolius Tuckerm	Large-leaved pondweed	31	42	0.07
Potamogeton foliosus Raf.	Leafy pondweed	2	0	—
Potamogeton gramineus L.	Variableleaf pondweed	1	0	—
Potamogeton natans L.	Floating-leaved pondweed	4	3	0.71
Potamogeton praelongus Wulf.	Whitestem pondweed	<1	24	<0.01
Potamogeton richardsonii (Ar. Benn.) Rydb.	Clasping-leaved pondweed	1	6	0.05
Potamogeton robbinsii Oakes	Robbins' pondweed	52	66	0.01
Potamogeton zosteriformis Fern.	Flat-stemmed pondweed	13	17	0.53
Ranunculus aquatilis L.	White water-buttercup	5	2	0.25
Vallisneria americana Michx.	Wild celery	2	5	0.25
Native Species Richness (per point)		1.5 ± 0.1	2.1 ± 0.1	<0.01
Non-native Species Richness (per point)		0.2 ± 0.0	0.0 ± 0.0	<0.01
Mean Water Depth (m)		3.1 ± 0.6	3.2 ± 0.6	

Table 2. Herbicide residue samples collected in Hayden Lake during July, August, and September 2007. Applications were made on July 30 and 31 2007, concentrations reported in mg L^{-1}. Residue data reprinted with permission from the Inland Empire Cooperative Weed Management Area, ID.

Location[a]	Herbicide	1 DAT	2 DAT	3 DAT	4 DAT	14 DAT	42 DAT
Chicken Point	Triclopyr	—	0.00	—	—	—	—
Cooper Bay	Triclopyr	0.00	—	—	—	—	—
McLean's Bay	Triclopyr	0.58	0.33				—
Shenandoah	Triclopyr	0.07	—	—	—	—	—
Sunset Beach	Triclopyr	0.02	—	—	—	—	—
Welbourne	Triclopyr	0.00	0.02	—	—	—	—
Clark's Bay	2,4-D	0.28	0.15	0.10	-	-	0.00
Mokins Slough	2,4-D	—	0.35	0.47	0.33	0.26	0.002
O'Rourke Bay	2,4-D	0.35	0.47	0.31	0.29	0.01	0.002
Preston Beach	2,4-D	—	0.36	0.17	0.28	0.13	0.001
Schmidt's Bay	2,4-D	0.00	—	—	—	—	0.00
Sportsman's Bay	2,4-D	0.07	0.17	0.28	0.17		0.00
Victoria Bay	2,4-D	—	0.71	0.16	0.18	0.18	0.00

[a]Not all treated areas were sampled for herbicide residues.

Water samples collected in 2,4-D treated areas showed residues between 0 and 0.71 mg ae L^{-1} 1 to 2 DAT (Table 2). Based on concentration exposure time relationships, a 2,4-D concentration of 0.25 mg ae L^{-1} should yield >85% control if maintained for at least 72 hr (Netherland and Getsinger 1992). Herbicide residues of 0.10 to 0.47 mg ae L^{-1} were reported at 3 to 4 DAT in most 2,4-D treated areas. The slower rate of dissipation and degradation of 2,4-D compared to triclopyr is likely due to the slow release of 2,4-D from the granular formulation, as opposed to the use of the triclopyr in a liquid formulation. Observed control of Eurasian watermilfoil in Hayden Lake 2,4-D plots (57 ha) was 83%. Like triclopyr, 2,4-D offered excellent control of Eurasian watermilfoil 5 WAT. The use of granular 2,4-D resulted in significant reductions in the Eurasian watermilfoil population in Lake Quonnipaug, Connecticut (Bugbee and White 2004). Likewise, granular 2,4-D was efficacious in removing variable watermilfoil (*Myriophyllum heterophyllum*) in Bashan Lake, Connecticut (Bugbee et al. 2003). The use of 2,4-D is common in Eurasian watermilfoil control programs and has typically offered control during large scale treatments in lakes with little to no nontarget plant injury (Couch and Neslon

TABLE 3. FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES OBSERVED DURING THE PRE-TREATMENT AND POST TREATMENT SURVEYS OF THE HERBICIDE APPLICATION AREAS IN HAYDEN LAKE, 2007. WATER DEPTH AND SPECIES RICHNESS ARE REPORTED AS THE MEAN ± 1 SE. SIGNIFICANCE VALUES WERE DETERMINED USING THE MCNEMAR'S TEST AT P = 0.05; P-VALUES COULD NOT BE COMPUTED FOR THOSE SPECIES WITH A 0 PERCENT OCCURRENCE REPORTED DURING EITHER SURVEY.

Species	Common Name	% Occurrence Pre Treatment	% Occurrence Post Treatment	% Change[a]	p-value
Callitriche sp.	Water-starwort	1	0		—
Ceratophyllum demersum L.	Coontail	19	16		0.66
Chara sp.	Muskgrass	0	4		—
Elodea canadensis Michx.	Elodea	39	39		0.99
Juncus pelocarpus Mey.	Rush	7	4		0.10
Myriophyllum sibiricum Komarov	Northern watermilfoil	0	2		—
Myriophyllum spicatum L.	Eurasian watermilfoil	34	4	- 88	<0.01
Najas flexilis (Willd.) Rostk. & Schmidt	Slender naiad, bushy pondweed	0	2		—
Nitella sp.	Nitella	5	0		—
Nuphar lutea L.	Yellow pond-lily	9	12		0.41
Potamogeton amplifolius Tuckerm	Large-leaved pondweed	13	42	+69	<0.01
Potamogeton crispus L.	Curlyleaf pondweed	1	2		0.65
Potamogeton epihydrus Raf.	Ribbonleaf pondweed	0	2		—
Potamogeton foliosus Raf.	Leafy pondweed	4	0		—
Potamogeton gramineus L.	Variableleaf pondweed	1	2		0.31
Potamogeton natans L.	Floating-leaved pondweed	6	5		0.73
Potamogeton praelongus Wulf.	Whitestem pondweed	16	10		0.06
Potamogeton richardsonii (Ar. Benn.) Rydb.	Clasping-leaved pondweed	3	2		0.70
Potamogeton robbinsii Oakes	Robbins' pondweed	50	70	+29	<0.01
Potamogeton zosteriformis Fern.	Flat-stemmed pondweed	19	14		0.14
Ranunculus aquatilis L.	White water-buttercup	6	2		0.06
Vallisneria americana Michx.	Wild celery	1	7	+90	0.01
Native Species Richness (per point)		1.9 ± 0.1	2.3 ± 0.1		<0.01
Non-native Species Richness (per point)		0.4 ± 0.1	0.1 ± 0.0		0.02
Mean Water Depth (m)		2.3 ± 0.3	2.1 ± 0.4		—

[a]Percent change is only reported for species showing a statistically significant change.

1982, Getsinger et al. 1982, Parsons et al. 2001). In Loon Lake and Lake Osoyoos, Washington, the use of 2,4-D resulted in >85% control of Eurasian watermilfoil 1 year after treatment (Killgore 1984, Parsons et al. 2001).

The use of herbicides to control Eurasian watermilfoil had no significant negative impact on the native plant community. In general, the occurrence of most species did not significantly change after herbicide application (Table 3); however, the occurrence of large-leaved pondweed, Robbins' pondweed, and wild celery increased by 69% ($p < 0.01$), 29% ($p < 0.01$), and 90% ($p = 0.01$), respectively. As a taxonomic group, the native pondweeds comprised the majority of plant species observed in Hayden Lake. The prevalence of monocot species is significant because these plant species are minimally affected by auxin herbicides (Sprecher and Stewart 1995, Sprecher et al. 1998), and in this study on Hayden Lake there were no significant adverse effects of herbicide applications on monocot or native dicotyledon species (dicot). In fact, it seems that the removal of Eurasian watermilfoil may have been a factor in increasing the presence of some plant species.

Other studies have documented that native species will recolonize those areas where Eurasian watermilfoil was removed. In the Pend Oreille River, Washington, Getsinger et al. (1997) reported that monocot species more than doubled in average diversity within treated areas, both 1 and 2 years after treatment. The increase in species diversity was attributed to the emergence of native pondweed species following the herbicide treatment. This same study reported that the dicot community was impacted initially by the application of triclopyr; however, once the Eurasian watermilfoil was removed native dicot species actually increased in abundance (Getsinger et al. 1997). In Loon Lake, Washington, the use of 2,4-D significantly reduced Eurasian watermilfoil presence and biomass while not significantly impacting the native plant community (Parsons et al. 2001). The removal of Eurasian watermilfoil and its canopy increases light penetration into the water column and increases available space for plant colonization, which results in increased growth of and competition from native species. Increases in native species may deter recolonization by Eurasian watermilfoil (Madsen 1994).

The presence of Eurasian watermilfoil in Hayden Lake was significantly reduced following the application of herbicides. The use of the point intercept survey facilitated the quantitative assessment of a lake-wide Eurasian watermilfoil control program for Hayden Lake, and also allowed quantitative documentation and tracking of native plant species over the growing season. The use of these herbicides resulted in the selective removal of Eurasian watermilfoil with no significant negative impact to native plant species. In fact, the removal of Eurasian watermilfoil may have resulted in increases in some native pondweeds and wild celery. Future applications of triclopyr and 2,4-D in Hayden Lake should have minimal to no detrimental/negative impact on the native plant community based on these findings. No single treatment of any herbicide is likely to eradicate all the invasive species in 1 year; long-term management will require persistent monitoring, management activity, and assessment of that activity. A long-term management plan should be developed and incorporate not only year-of-treatment management evaluations, but also long-term monitoring of the aquatic plant community. Intensive monitoring has been cited as the only effective way to determine a program's success and when to terminate a management program (Simberloff 2003).

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